Science-Quality Oscillators for Deep Space Probes

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Planetary spacecraft and probes carry oscillators as clocks for purposes of telecommunications, navigation, and mission timekeeping. In many cases, radio science experiments also utilize oscillators and typically push the limits of their stability in order to optimize science return, especially atmospheric physics. The number of design options for oscillators has increased, offering lower cost and mass and sufficient stability performance for non-scientific applications. Since the designation label Ultra-Stable Oscillator was coined, new ones such as Sufficiently Stable Oscillators have entered into usage with each label applied to models that vary by one or more orders of magnitude in frequency stability, causing misunderstandings in the usage. Additionally, inquiries have increased on the usage of crystal oscillators (e.g., Galileo probe) over atomic frequency standards using rubidium gas cells (e.g., Huygens) or cesium beam tubes, where characteristics vary in relevant parameters such stability after long vs. short turn-on time, long-term drift, phase noise, etc. Finally, the most stable to date atomic clock will soon be qualified for space flight, further increasing the options, especially for science applications. This paper will provide a comprehensive review of available oscillators for deep space science payloads with practical performance trades for the type of mission architectures and requirements. A formalization of the oscillator labels for given stability levels will be proposed and a summary of typical radio science requirements will be presented.